Spatially explicit models of occupancy for evaluating forest restoration and climate change on the Kaibab National Forest, Arizona

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Introduction

Motivation

Severe wildfires and vegetation type conversions are likely to increase across the western United States as temperatures rise and droughts become more common (Cocke et al. 2005, Notaro et al. 2012). This condition is exacerbated by an historic inability for forest restoration treatments to keep pace with fire risk often due to disagreements about impacts on wildlife species and the challenges associated with monitoring those impacts.

Figure 1. Study site location, the Kaibab National Forest, Arizona, USA.

The Kaibab National Forest (Arizona, USA) has sought to address these concerns during its current Land and Resource Management Plan revision process by leveraging both ground-based and remotely sensed information to develop landscape-scale, spatially explicit models of occupancy for several passerine species.

Figure 2. Changing climate and its interaction with high severity fire can have profound impacts on southwestern forest communities resulting in altered forest structure and community composition From left: old-growth ponderosa pine (*Pinus ponderosa*) forests on the Kaibab Plateau (Arizona, USA); the 2006 Warm Fire on the Kaibab Plateau; Cheatgrass (Bromus tectorum) invasion following the 1996 Bridger Knoll fire complex on the Kaibab Plateau.

Songbird occupancy and monitoring

Songbirds are commonly selected for monitoring programs to assess the impacts of landscape change due to their sensitivity to changes in vegetation structure and composition because they are thought to be responsive to a variety of "environmental quality" attributes (Saracco et al. 2008; Dickson et al. 2009).

Occupancy as a monitoring variable (from Noon et al. 2012):

- Relates to likelihood of persistence
- Controls for imperfect detection
- Provides estimation efficiency

Spatially explicit occupancy models allow:

- estimation of changes in species distribution across the landscape
- affords the ability to infer the effects of landscape change.

Here we demonstrate the utility of this approach using results from Grace's Warbler (*Dendroica graciae*), Ruby-crowned Kinglet (*Regulus calendula*), and Western Bluebird (*Sialia mexicana*).

Figure 3. Passerine species evaluated by the Kaibab National Forest as potential indicators for use in Forest monitoring.

Objectives

Spatially Explicit Occupancy Models Should:

1) Identify important habitat components likely to change as a function of land management or climate change

2) Provide a means to monitor the effects of landscape change (e.g., fire, restoration treatments, or climate change) at broad spatial extents

3) Provide the ability to explore trade-offs through simulation of the effects of land management or climate change

Methods

Avian Surveys: Conducted by the US Forest Service and Rocky Mountain Bird Observatory across the Kaibab National Forest from 2006 – 2009 (Hanni et al. 2009).

Habitat Covariates: Derived for 2006 and 2010 from Landsat 5 TM imagery and USDA Forest Service Forest Inventory and Analysis plots, interagency LANDFIRE data for vegetation type, and derivatives of the National Elevation Dataset. All data were standardized and smoothed to 125m radius to coincide with bird survey transects.

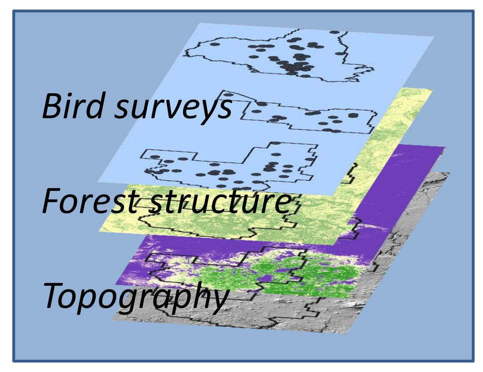

Figure 4. Heuristic depiction of the "stacking" of forest structural variables for the development of spatial models.

Occupancy estimates: Spatial models of occupancy were built using the single season model of MacKenzie et al. (2006) and 2006 forest structural covariates. All parameter estimates were model-averaged to account for model uncertainty (Burnham & Anderson 2002). Models were fit in PRESENCE (v2.2; Hines 2006).

Results: Important habitat features

Model selection results indicate that occupancy for each species is sensitive to changes in habitat covariates that are likely to change as a function of land management.

	Grace's Warbler			Ruby-crowned Kinglet			Western Bluebird		
Covariate	$\tilde{\beta}$	SE	Z	$\tilde{\beta}$	SE	Z	$\tilde{\beta}$	SE	Z
Basal area	4.02	1.18	3.42	1.19	0.43	2.73	0.46	0.69	0.67
Basal area squared	—	—	—	-0.19	0.34	-0.57	-0.80	0.44	-1.80
Standard deviation of basal area	1.03	0.67	1.54	-0.04	0.11	-0.35	0.20	0.36	0.56
Standard deviation of tree density	-0.99	0.62	-1.59	0.48	0.30	1.58	—	—	—
Canopy cover (≤21.03%)	4.71	2.28	2.06	—	—	—	—	—	—
Canopy cover (21.03%<x≤46.56%)	2.41	1.20	2.01	-1.25	0.66	-1.91	—	—	—
Canopy Cover (≤35%)	—	—	—	—	—	—	0.89	1.14	0.78
Ponderosa pine vegetation type	—	—	—	-1.87	0.70	-2.67	2.39	0.95	2.52
Mixed-conifer vegetation type	0.16	0.38	0.43	—	—	—	-0.54	0.71	-0.75
Variation in vegetation type	0.26	0.38	0.67	—	—	—	0.08	0.17	0.49
Northeastern orientation	-0.02	0.08	-0.28	—	—	—	0.02	0.07	0.31
Intercept	*-3.40*	*1.65*	*-2.06*	*0.50*	*0.60*	*0.83*	*0.53*	*0.74*	*0.72*

Table 1. Model-averaged regression coefficients (β), unconditional standard errors (SE), and Z-statistics (*Z*) for habitat variables included in the best model(s) (AIC<4.0) of occupancy for Grace's Warbler, Ruby-crowned Kinglet, and Western Bluebird on the Kaibab National Forest (Arizona, USA). "Important" (*Z* > 2) variables are highlighted in orange. Variables that were not estimated because they were absent from the best model set are denoted as "—". Full results in Dickson et al. 2011.

Results: Monitoring at landscape scales

Occupancy models allow assessment of trend over broad spatial and temporal scales while reducing bias due to imperfect detection.

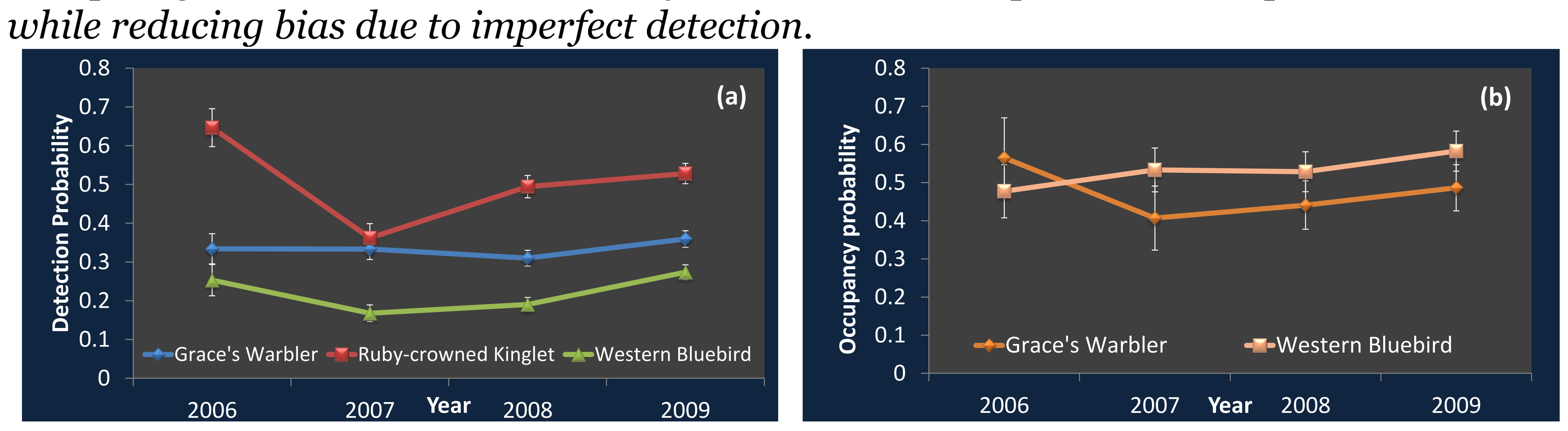

Figure 5. Annual estimates for detection probability (a) and occupancy (b) for Grace's Warbler, Ruby-crowned Kinglet, and Western Bluebird for the Kaibab National Forest (Arizona, USA). Occupancy estimates for Ruby-crowned Kinglet are omitted due to insufficient sample size.

A) Grace's Warbler B) Ruby-crowned Kinglet C) Western Bluebird

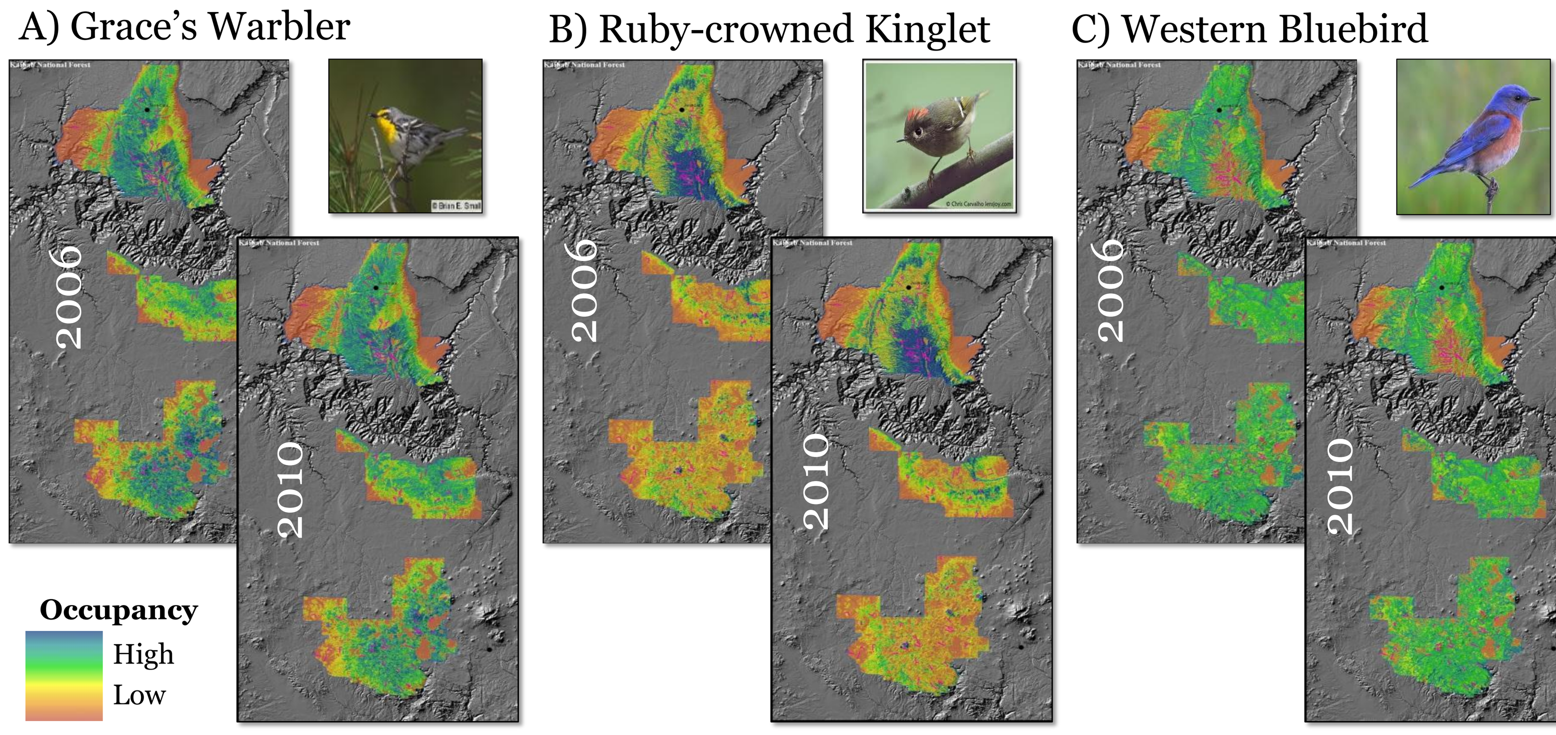

Figure 6. Occupancy models for Grace's Warbler (GRWA,A), Ruby-crowned Kinglet (RCKI,B), and Western Bluebird (WEBL,C) on the Kaibab National Forest (Arizona, USA) in 2006 and 2010. Model-averaged regression coefficients appear in Table 1.

Extensions: Evaluating alternatives

A) GRWA (2006) B) GRWA (2010)

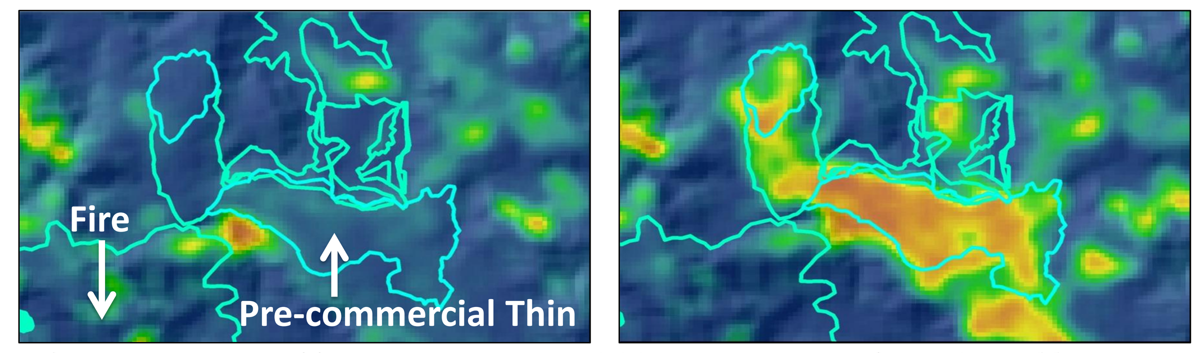

Figure 7. Impacts of forest management activities on occupancy of Grace's Warbler.

Occupancy models and forest management

Using remotely sensed, "digital" inputs allows land managers and stakeholders to create alternative management scenarios and evaluate their effects on species of interest. Further, the ability to look retrospectively at previous management activity (Figure 7) provides the ability to ensure that scenarios reflect "real-world" events.

A) RCKI Occupancy B) RCKI Occupancy following PIPO shift C) Change in RCKI Occupancy

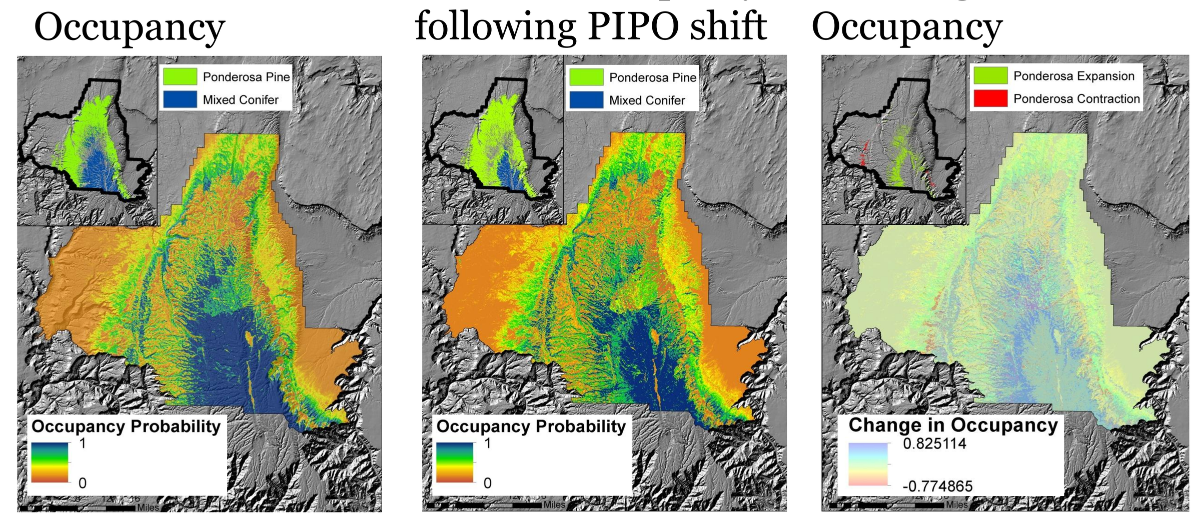

Figure 8. Predicted effects of a 150m elevational shift in ponderosa pine (inset) on Ruby-crowned Kinglet on the North Kaibab Ranger District of the Kaibab National Forest.

Occupancy models and a changing climate

The use of "digital" inputs also allows manipulation of various forest structural elements to identify the effects of climate change on species distribution at sub-regional scales. Simple manipulation of the extent of vegetation types (Figure 8) has clear implications; however, it is likely that climate change will impact a variety of forest structural attributes. These models provide an initial step to understanding those impacts on these species.

Discussion

Spatially explicit occupancy models are well-suited to identify key habitat attributes likely to be affected by land management activity, monitoring across broad spatial extents, and evaluating future scenarios for Grace's Warbler, Ruby-crowned Kinglet, and Western Bluebird. Here we used species of interest to the Kaibab National Forest; however, other species more sensitive to landscape change or multi-species composite models may provide more information on the impacts landscape change on biodiversity. We also focused on a subset of habitat covariates that were: a) projected to change as a function of management or climate change and b) could be reliably derived from satellite imagery. Future efforts will focus on including additional biologically important covariates use of hierarchical modeling techniques to evaluate relationships at multiple scales.

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